CONSIDERING ORBIT CHANGES FOR THE TRACKING AND DATA RELAY SATELLITE SYSTEM [Ψ]

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ABSTRACT

The possibility of a collision of a Tracking and Data Relay Satellite System (TDRSS) satellite with another orbiting object is a matter of concern to NASA. One hypothesis being investigated is that by slightly altering the TDRSS satellite orbits with changes to eccentricity and argument of perigee (AOP), the number of possible conjunctions between the TDRSS fleet members and other satellites and debris would decrease. This paper presents the results of analysis completed to verify this hypothesis.

INTRODUCTION

More than 8,500 objects are currently being monitored as they orbit the Earth, Figure 1. The possibility of close approaches and possible collisions with other spacecraft and orbiting debris is a matter of concern for all space based missions. An Orbital Debris Colloquium held at Goddard Space Flight Center (GSFC) in March 2002 (Ref. 1) re-focused attention on the problem and the associated risks.

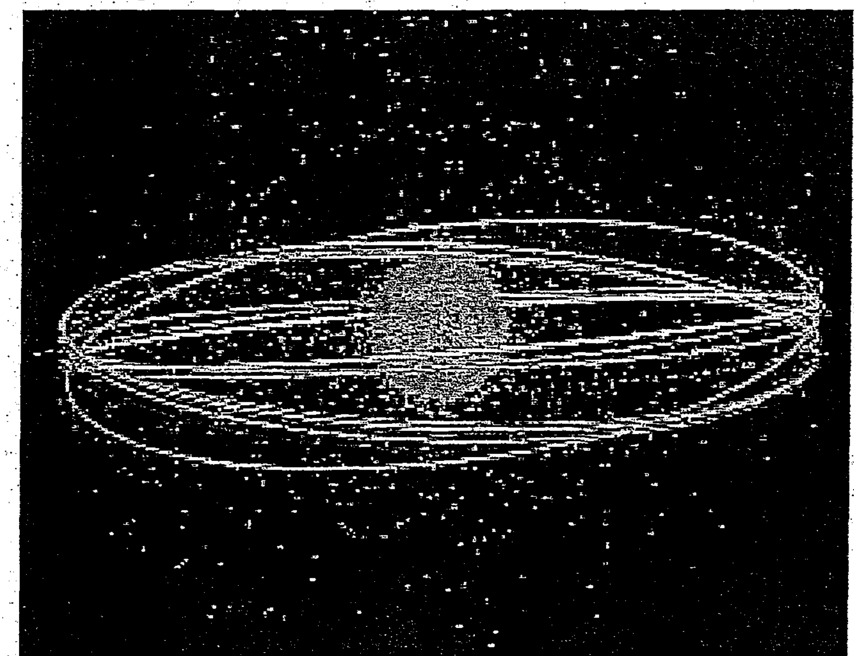

Figure 1. Objects currently being monitored as they orbit the Earth with TDRSS orbits highlighted.

The possibility of close approaches and collisions affecting the TDRSS is of interest to NASA. One hypothesis being investigated is that by slightly altering the orbits with changes to eccentricity and argument of perigee of the TDRSS fleet, the number of possible conjunctions between the TDRSS fleet members and other satellites and debris will be decreased. This paper presents the results of an investigation done on the effects of increasing the eccentricities and changing the AOP of the TDRS on the potential number of conjunctions. Risk analysis was not the intent of this investigation and, therefore, was not attempted.

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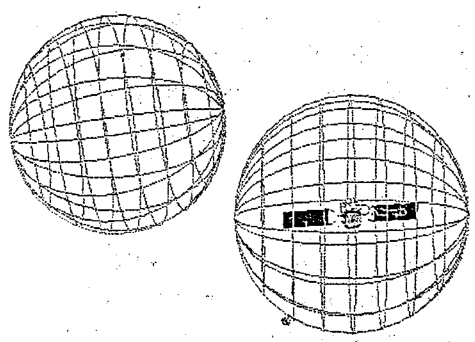
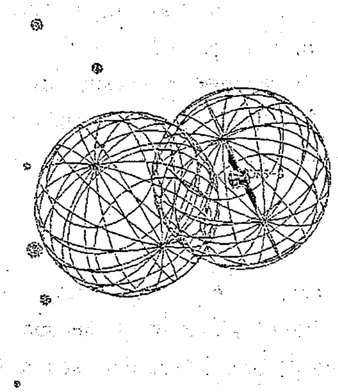
APPROACH

The basic approach used for this analysis was repeated propagations of the orbits of the Tracking and Data Relay Satellite (TDRSs) and objects that are potential conjunctors for 6 weeks. The TDRS orbits were varied with each propagation. Each object, TDRSS and non-TDRSS, was considered to have a conjunction bubble of 100km radius, Figure 2. The number of conjunctions, where a conjunction is defined as a close approach such that the TDRS bubble intersected the bubble of another object, was counted and their closest approach distances tabulated. The propagation did not include maneuvers of the TDRSS fleet or other satellites. The purpose of the study is to gain a measure of the conjunction possibility, and is not to predict specific conjunctions.



Each TDRSS and non-TDRSS object represented by a conjunction bubble with a radius of 100km



A conjunction is defined as the intersection of the conjunction bubbles of a TDRSS and non-TDRSS object.

Figure 2. Identifying conjunctions between TDRSS and non-TDRSS objects.

The initial conditions for the non-TDRSS objects were obtained from the two-line element (TLE) catalog from NORAD that contains TLEs for all 8,500 unclassified objects in orbit around Earth as of 15 February 2005. Using the Satellite Tool Kit (STK) v6.0.2 and the Advanced Conjunction Analysis Tool (AdvCat) module, each individual TDRS was specified as a primary satellite and the TLE catalog objects were specified as secondaries. The use of pre-filters to remove NORAD objects in orbits that never intersect geosynchronous orbit (i.e., LEO or outside GEO) decreased the processing time significantly. For example, for TDRS-8, after the filters were applied, there were 18 secondary objects left to process. All secondary objects whose 100 km bubble intersected the primary's 100 km bubble were noted. The AdvCAT module selected those objects and propagated those TLEs through 31 March 2005 using the Single Point Ground (SPG4) technique. The number of conjunctions between the TDRS and any other tracked object was counted during the time span and the distance of closest approach recorded.

Three scenarios were considered to better understand the effects of orbit changes for the TDRSS fleet on the number of conjunctions experienced by the individual satellites comprising the fleet. For each scenario, the number of conjunctions and the proximity of these conjunctions were evaluated. For the first scenario, eccentricity was varied over a range of values while maintaining the nominal AOP for each of the TDRSS fleet members. For the second scenario, eccentricity was varied over a range of values while maintaining an AOP of 0 degrees for each of the TDRSS fleet members. For the third scenario, AOP was varied over a range of values while maintaining the nominal eccentricity for each of the TDRSS fleet members. Table 1 summarizes the various eccentricity and AOP values used for each scenario for each of the TDRSS fleet members.

Table 1. Key TDRSS orbital parameter values for each of the scenarios considered. Nominal values are in bold.

TDRS	Scenario[1]	Eccentricity[2]	AOP
1	1	0. and **0.0006609** through 0.0016609	**220**
	2	0. and **0.0006609** through 0.0016609	0
	3	**0.0006609**	0, 60, 180, **220**, 310
3	1	0. and **0.0006107** through 0.0016107	**330**
	2	0. and **0.0006107** through 0.0016107	0
	3	**0.0006107**	0,60, 150, 180, **330**
4	1	0. and **0.0002737** through 0.0012737	**261**
	2	0. and **0.0002737** through 0.0012737	0
	3	**0.0002737**	0, 81, 180, **261**, 351
5	1	0. and **0.0001861** through 0.0011861	**253**
	2	0. and **0.0001861** through 0.0011861	0
	3	**0.0001861**	0, 73, 180, **253**, 343
6	1	0. and **0.0003676** through 0.0013676	**292**
	2	0. and **0.0003676** through 0.0013676	0
	3	**0.0003676**	0, 22, 112, 180, **292**
7	1	0. and **0.00141051** through 0.00241051	**198**
	2	0. and **0.00141051** through 0.00241051	0
	3	**0.00141051**	0, 18, 180, **198**, 288
8	1	0. and **0.0002887** through 0.0012887	**50**
	2	0. and **0.0002887** through 0.0012887	0
	3	**0.0002887**	0, **50**, 140, 180, 230
9	1	0. and **0.0003796** through 0.0013796	**35**
	2	0. and **0.0003796** through 0.0013796	0
	3	**0.0003796**	0, **35**, 125, 180, 215
10	1	0. and **0.0003772** through 0.0013772	**16**
	2	0. and **0.0003772** through 0.0013772	0
	3	**0.0003772**	0, **16**, 106, 180, 196

1 - Scenario 1: Eccentricity varied with nominal AOP
Scenario 2: Eccentricity varied with 0.0 degrees AOP
Scenario 3: Eccentricity nominal with varied AOP

2 - step size of 0.0002 used when varying eccentricity

RESULTS

For each of the scenarios evaluated, data on the number of conjunctions experienced by each member of the TDRSS fleet were tabulated. This information is presented throughout the remainder of this section.

An additional study was conducted for TDRS-3 to more thoroughly characterize the relationship between changes in eccentricity and AOP on the number of conjunctions for that spacecraft. This study was prompted by the relatively large number of conjunctions observed for TDRS-3 when compared to the other members of the TDRSS fleet and the direct relationships identified between changes in orbital parameters and the resulting number of conjunctions observed for this spacecraft. The reason for the large number of conjunctions for TDRS-3 is not known and was not investigated.

Scenario 1: Varying Eccentricity with Nominal AOP

The effects of varying the eccentricity over a range of values (Table 1) while maintaining the nominal AOP for each of the TDRSS fleet members are illustrated in Figure 3. The unfilled plot icons in Figure 3 indicate the nominal eccentricity for each TDRS. Generally speaking, independent of the size of the bubble used to evaluate the number of conjunctions (Tables 2 through 10), relatively few changes in the number of conjunctions occurs as the eccentricity is varied with nominal AOP. Changing the eccentricity for TDRS 3 appears to directly result in a decrease in the number of conjunctions. Changing the eccentricity for TDRS 4, 5, 8, and 10 has little to no effect on the number of conjunctions each of these TDRS would experience over the 6-week time span considered. TDRS 1 shows a similar trend after increasing the eccentricity by at least .0008. In the cases of TDRS 6, 7 and 9, it appears that increasing the eccentricity will actually increase the number of possible conjunctions over the given time span.

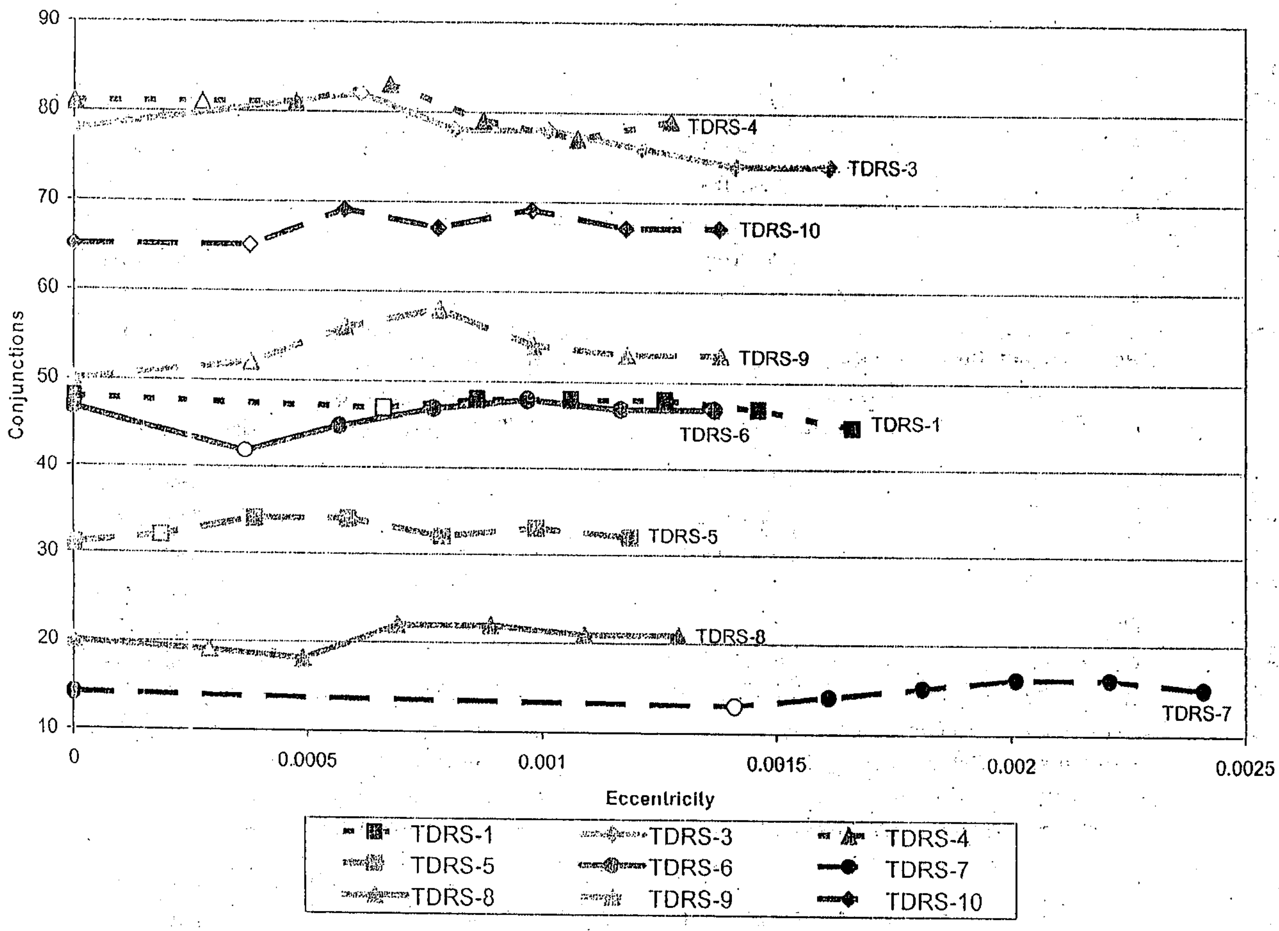
It should be noted that, for an orbit that is circular with a 42,300 km semi-major axis, changing the eccentricity by .001, the largest increment used, produces a change in apogee and perigee of 42.3 km. This is smaller than the conjunction bubble-size that was used.

Scenario 2: Varying Eccentricity with 0 Degree AOP

The effects of varying the eccentricity over a range of values (Table 1) while maintaining a 0 degree AOP for each of the TDRSS fleet members are illustrated in Figure 4. The unfilled plot icons in Figure 4 indicate the nominal eccentricity for each TDRS. The trends identified when varying the eccentricity with a nominal AOP in scenario 1 were also observed in this scenario and relatively few changes in the number of conjunctions occurs as the eccentricity is varied with 0 degree AOP.

Scenario 3: Varying AOP with Nominal Eccentricity

The effects of varying the AOP over a range of values (Table 1) while maintaining a nominal eccentricity for each of the TDRSS fleet members are illustrated Figure 5. The unfilled plot icons in Figure 5 indicate the nominal AOP for each TDRS. It is clear from the data that changing the AOP has a more significant effect on the number of conjunctions experienced by the TDRSS fleet members than simply varying the eccentricity. The data from the AOP study of TDRS 1 is inconclusive. It appears, however, that changing TDRS 4's AOP to something closer to 80 degrees, as opposed to its nominal value of 261 degrees, would decrease conjunctions appreciably. The AOP data further suggest that TDRS 5's and TDRS 6's AOP are at the optimal values to avoid the most conjunctions.



key orbital parameters

TDRS	Eccentricity[1]	AOP
1	0, **0.0006609** to 0.0016609	220
3	0, **0.0006107** to 0.0016107	330
4	0, **0.0002737** to 0.0012737	261
5	0, **0.0001861** to 0.0011861	253
6	0, **0.0003676** to 0.0013676	292
7	0, **0.00141051** to 0.00241051	198
8	0, **0.0002887** to 0.0012887	50
9	0, **0.0003796** to 0.0013796	35
10	0, **0.0003772** to 0.0013772	16

1 - step size of 0.0002 degrees when varying eccentricity

Figure 3. Scenario 1 - Number of Conjunctions Observed when Varying Eccentricity with Nominal AOP

Table 2. TDRS-1 conjunctions when varying eccentricity with nominal AOP.

	Number of conjunctions within			
Eccentricity	25 km	50 km	100 km	200 km*
0	3	8	20	48
0.0006609	1	9	20	47
0.0008609	2	8	19	48
0.0010609	2	7	19	48
0.0012609	2	8	17	48
0.0014609	0	6	17	47
0.0016609	0	4	17	45

Table 3. TDRS-3 conjunctions when varying eccentricity with nominal AOP.

	Number of conjunctions within			
Eccentricity	25 km	50 km	100 km	200 km*
0	0	3	26	78
0.0006107	**1**	**4**	**25**	**82**
0.0008107	1	4	24	78
0.0010107	1	4	24	78
0.0012107	1	3	21	76
0.0014107	1	3	20	74
0.0016107	1	3	18	74

Table 4. TDRS-4 conjunctions when varying eccentricity with nominal AOP.

	Number of conjunctions within			
Eccentricity	25 km	50 km	100 km	200 km*
0	5	9	30	81
0.0002737	**5**	**9**	**29**	**81**
0.0004737	4	9	29	81
0.0006737	5	11	30	83
0.0008737	4	10	29	79
0.0010737	4	11	29	77
0.0012737	6	14	29	79

Table 5. TDRS-5 conjunctions when varying eccentricity with nominal AOP.

	Number of conjunctions within			
Eccentricity	25 km	50 km	100 km	200 km*
0	0	3	11	31
0.0001861	**0**	**2**	**11**	**32**
0.0003861	1	2	10	34
0.0005861	1	2	12	34
0.0007861	0	2	12	32
0.0009861	1	3	11	33
0.0011861	1	3	11	32

Table 6. TDRS-6 conjunctions when varying eccentricity with nominal AOP.

	Number of conjunctions within			
Eccentricity	25 km	50 km	100 km	200 km*
0	2	10	22	47
0.0003676	**1**	**8**	**20**	**42**
0.0005676	0	6	19	45
0.0007676	0	5	18	47
0.0009676	0	4	18	48
0.0011676	0	3	17	47
0.0013676	0	2	16	47

Table 7. TDRS-7 conjunctions when varying eccentricity with nominal AOP.

	Number of conjunctions within			
Eccentricity	25 km	50 km	100 km	200 km*
0	1	2	4	14
0.00141051	**0**	**1**	**4**	**13**
0.00161051	1	1	4	14
0.00181051	1	2	4	15
0.00201051	1	2	4	16
0.00221051	1	2	4	16
0.00241051	0	4	4	15

Table 8. TDRS-8 conjunctions when varying eccentricity with nominal AOP.

	Number of conjunctions within			
Eccentricity	25 km	50 km	100 km	200 km*
0	0	0	5	20
0.0002887	**0**	**0**	**4**	**19**
0.0004887	0	0	5	18
0.0006887	0	2	5	22
0.0008887	1	3	6	22
0.0010887	1	4	5	21
0.0012887	1	4	5	21

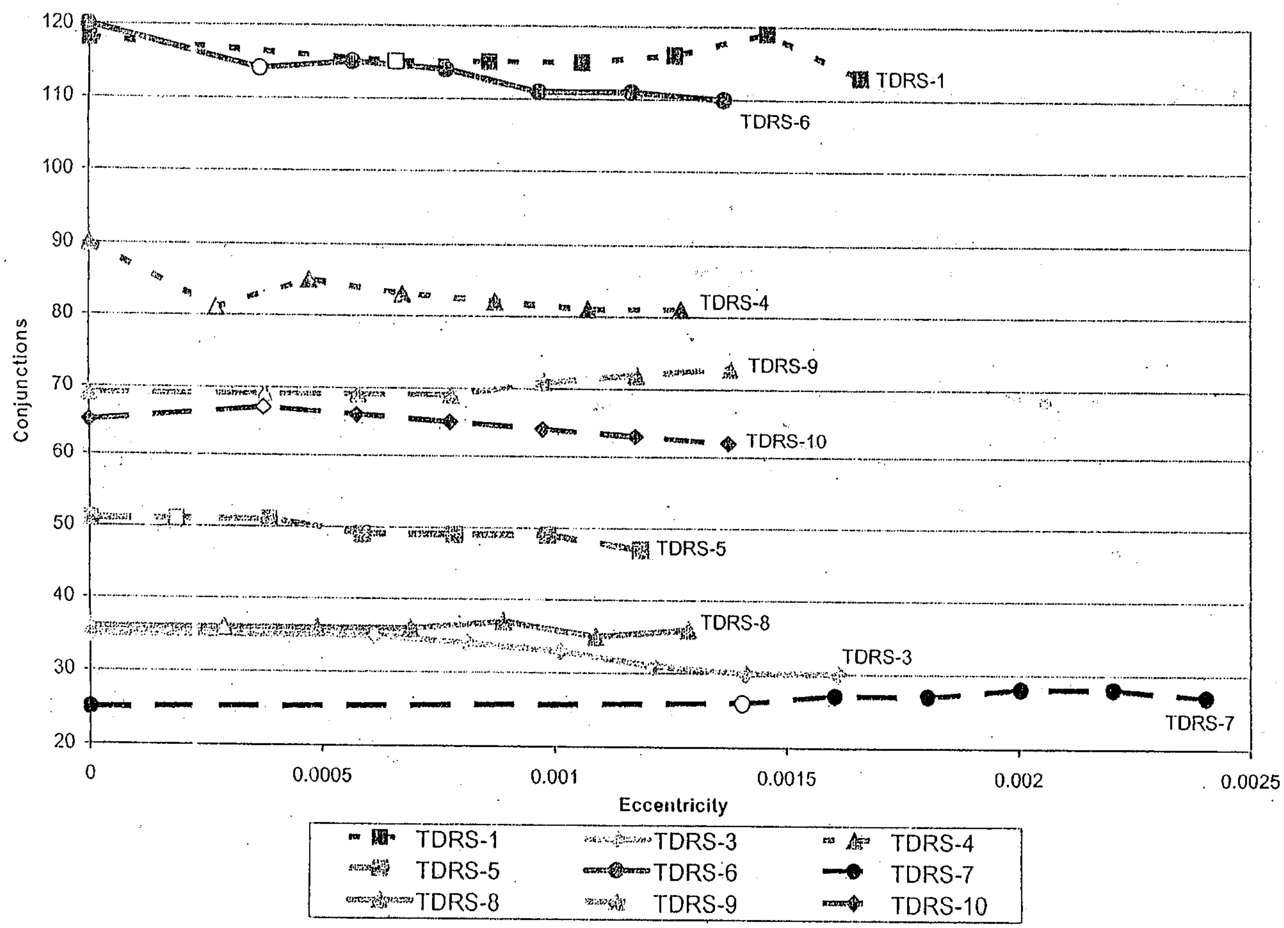
Table 9. TDRS-9 conjunctions when varying eccentricity with nominal AOP.

	Number of conjunctions within			
Eccentricity	25 km	50 km	100 km	200 km*
0	1	2	16	50
0.0003796	**1**	**3**	**17**	**52**
0.0005796	1	4	17	56
0.0007796	0	5	19	58
0.0009796	0	6	19	54
0.0011796	1	6	16	53
0.0013796	4	6	12	53

Table 10. TDRS-10 conjunctions when varying eccentricity with nominal AOP.

	Number of conjunctions within			
Eccentricity	25 km	50 km	100 km	200 km*
0	5	11	28	65
0.0003772	**4**	**11**	**26**	**65**
0.0005772	3	11	25	69
0.0007772	3	9	24	67
0.0009772	1	8	25	69
0.0011772	0	8	21	67
0.0013772	0	6	23	67

* - values plotted in Figure 1



key orbital parameters

TDRS	Eccentricity[1]	AOP
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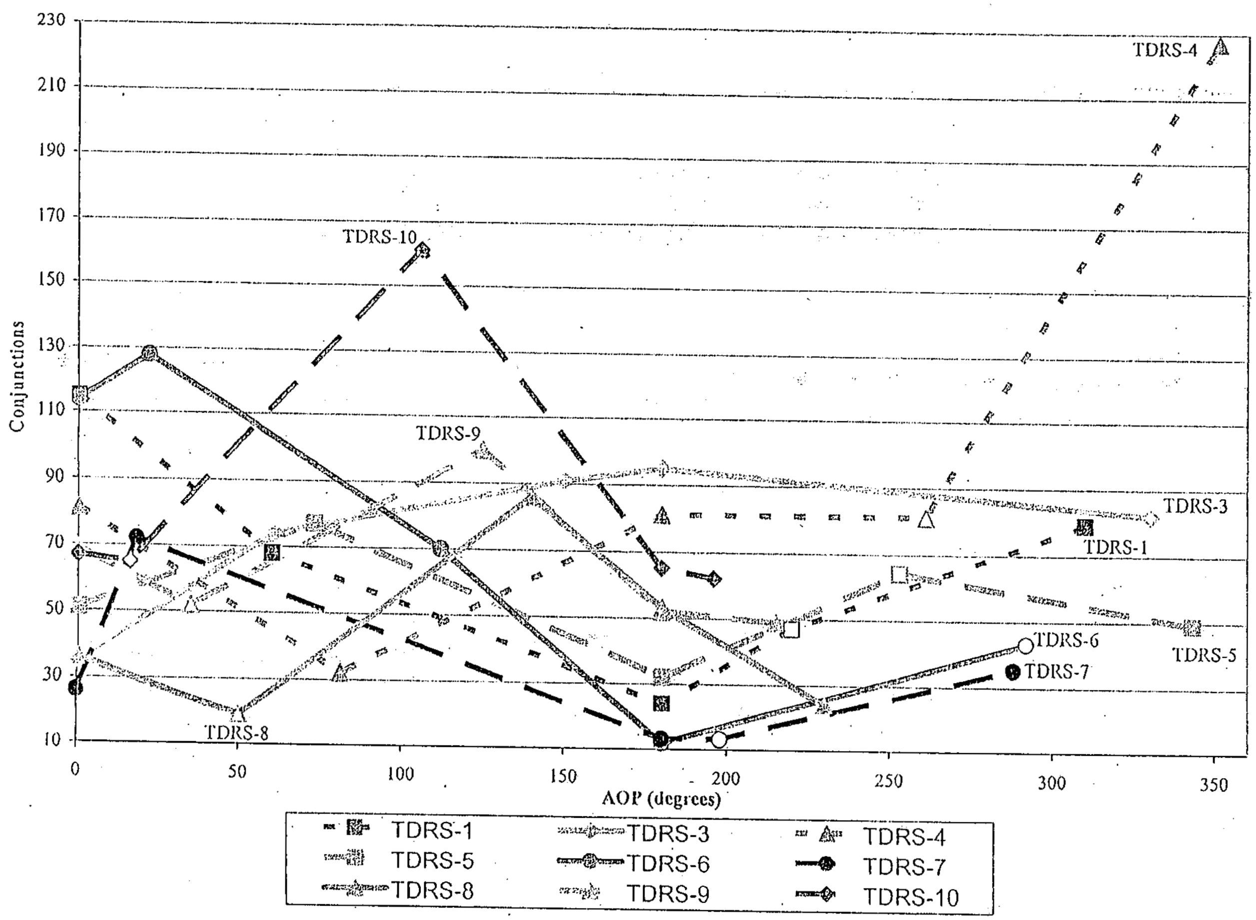
3	0, **0.0006107** to 0.0016107	0
4	0, **0.0002737** to 0.0012737	0
5	0, **0.0001861** to 0.0011861	0
6	0, **0.0003676** to 0.0013676	0
7	0, **0.00141051** to 0.00241051	0
8	0, **0.0002887** to 0.0012887	0
9	0, **0.0003796** to 0.0013796	0
10	0, **0.0003772** to 0.0013772	0

1 - step size of 0.0002 degrees when varying eccentricity

Figure 4. Scenario 2 - Number of Conjunctions Observed when Varying Eccentricity with 0 Degree AOP



key orbital parameters

TDRS	Eccentricity	AOP
1	0.0006609	0, 60, 180, 220, 310
3	0.0006107	0,60, 150, 180, 330
4	0.0002737	0, 81, 180, 261, 351
5	0.0001861	0, 73, 180, 253, 343
6	0.0003676	0, 22, 112, 180, 292
7	0.00141051	0, 18, 180, 198, 288
8	0.0002887	0, 50, 140, 180, 230
9	0.0003796	0, 35, 125, 180, 215
10	0.0003772	0, 16, 106, 180, 196

Figure 5. Scenario 3 - Number of Conjunctions Observed when Varying AOP with Nominal Eccentricity

Supplemental TDRS-3 Study

The relatively large number of conjunctions observed for TDRS-3 and TDRS-4 when compared to the other members of the TDRSS fleet prompted a supplemental study to more completely characterize the effects of varying the orbital parameters of these spacecraft. Because changes in the eccentricity appear to have a direct impact on the number of conjunctions for TDRS-3, as observed in scenario 1, TDRS-3 was selected for further study.

The data appear to indicate that increasing the TDRS 3 orbital eccentricity would directly decrease the number of conjunctions. However, the rate at which the number of conjunctions decreases compared to the required increase in eccentricity may not be worthwhile. A surface plot (Figure 6), which compares the number of conjunctions predicted at various AOP/eccentricity combinations, was prepared for TDRS 3. This plot clearly indicates that an AOP of 0 or 90 degrees would be favorable for lowering the number of possible conjunctions in the future and that an AOP of 135 degrees would not be an advisable position.

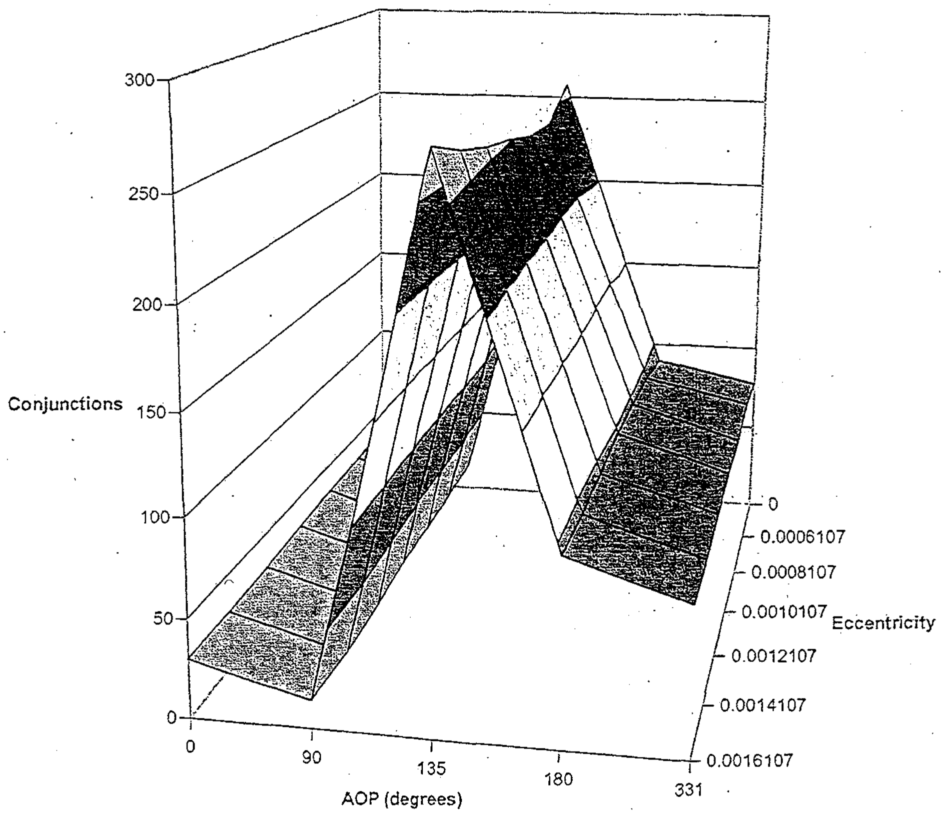


Figure 6. TDRS-3 Supplemental Study - Number of Conjunctions Observed with Various AOP/Eccentricity Combinations

CONCLUSION

While changing the eccentricities of the TDRSS fleet members would have some effect, positive or negative, on the possibility of a collision with another orbiting object, the effect would be minimal for most TDRSs. Changing the AOP of certain satellites, on the other hand, could have an appreciable and dramatic impact on the number of conjunctions. This is because changing the AOP rotates the line of apsides so the TDRSs have conjunctions with a different set of orbiting objects even though the size of the orbit does not change significantly with the eccentricity changes used in this analysis.

These results are from a statistical analysis of a standard approach to conjunction reduction based on modest orbital eccentricity changes and changes to the AOP. They indicate that the benefits of this approach are minimal and that the conjunctions are better managed with orbital modifications on a case-by-case basis.

REFERENCES

1. NASA Orbital Debris Colloquium at GSFC, presentation, March 2002